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Parazitace mořských hlaváčovitých ryb (Gobiidae, Perciformes) evropských vod mnohobuněčnými parazity

Parasitation of the European marine gobies (Gobiidae, Perciformes) by metazoan parasites

Bachelor thesis

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Prohlášení:

Prohlašuji, že jsem závěrečnou práci zpracovala samostatně a že jsem uvedla všechny použité informační zdroje a literaturu. Tato práce ani její podstatná část nebyla předložena k získání jiného nebo stejného akademického titulu.

V Praze, 14.5.2015

Podpis

Abstract

Gobiidae (Teleostei, Perciformes) is one of the most species-rich families of teleost fishes, comprising over 1,700 species currently recognized. They inhabit marine waters worldwide, with the exception of the Arctic and Antarctic regions, but also brackish and freshwater habitats. Mostly, they live inconspicuously on the bottom. They are usually small-sized, so they are suitable intermediate hosts in the transfer of parasites to larger fishes, or to birds and mammals. The main metazoan groups of parasites of gobies are Myxozoa, Monogenea, Digenea, Cestoda, Nematoda, Acanthocephala and Crustacea. Their life cycles and the known impact of parasites on fish physiology, fitness, behaviour and mortality are described. Additional effects on goby hosts such as the effect on reproduction and the effect on a female mate choice are mentioned, as well. The immunity response of fish to parasitation is briefly discussed. Finally, some special cases like parasitism in brackish and eutrophicated waters, and a difference in parasitation of gobies in protected and unprotected areas are discussed. Published works about parasitation of European marine gobies are scattered and usually are focussed on a single parasite species or group. The effects of a parasite on a goby are rarely described. Only some parts of European coast are well explored in a view of parasitation of marine gobies (e.g., the Baltic and the Black Seas).

Key words
Gobiidae, gobies, fish, parasites, marine, European

Abstrakt

Čeleď Gobiidae (Teleostei, Perciformes) s více než 1700 momentálně uznávanými druhy je jedna z největších čeledí kostnatých ryb. Hlaváči obývají celosvětově moře, s výjimkou Arktidy a Antarktidy, a také brakické a sladké vody. Většinou žijí skrytě na dně. Dorůstají malé velikosti, a tak jsou vhodnými mezihostiteli pro přenos parazitů do větších ryb, ptáků a savců. Hlavními skupinami mnohobuněčných parazitů hlaváčů jsou Myxozoa, Monogenea, Digenea, Cestoda, Nematoda, Acanthocephala a Crustacea. V práci jsou uvedeny životní cykly parazitů a je popsán dosud známý vliv parazitů na fyziologii, fitness, chování a úmrtnost ryb. Dále jsou zmíněny další efekty na hlaváče, jako je vliv na rozmnožování a na pohlavní výběr. Popsána je i imunita ryb. Nakonec je zařazen parasitismus v brakických a eutrofizovaných vodách. Publikované práce o parasitismu hlaváčů evropských moří přináší málo informací a většinou jsou zaměřeny na jednu skupinu parazitů, či popis nového druhu parazita. Vliv na hlaváče také není moc dobře znám. Jen některé části evropských břehů jsou z pohledu parazitismu mořských hlaváčů dobře prozkoumány (například Baltské či Černé moře).

Klíčová slova
Gobiidae, hlaváči, ryby, paraziti, mořských, evropských

Obsah

1 Introduction

The family Gobiidae belonging to the order Perciformes consists of over 1,700 species (Tornabene et al., 2013), which makes it one of the biggest families of teleost fishes. They inhabit marine waters worldwide, with the exception of Arctic and Antarctic areas, as well as brackish and freshwaters. Generally, they are small-sized, and short-lived, and they live inconspicuously on the substrate or hidden in various types of cavities. Among them there are benthic, hyperbenthic, cryptobentic and nektonic species (Kovačić & Patzner, 2011). They can serve to parasites as intermediate, paratenic, as well as final hosts. The transfer of parasites to gobies can be by direct contact (e.g., the case of monogeans belonging to *Gyrodactylus*), a larvae penetrating (e.g., digeneans *Cryptocotyle concavum* (Creplin, 1825), *Apatemon gracilis* Rudolphi, 1819, *Aphalloides timmi* Reimer, 1970, *Tylodelphis podicipina* Kozicka & Niewiadomska, 1960), or indirectly by consuming a prey (e.g., the digenean *Podocotyle atomon* (Rudolphi, 1802)), the cestode *Schistocephalus solidus* (Müller, 1776), the nematode *Hysterothylacium* sp. and the acantocephalan *Echinorhynchus gadi* Zoega, 1776) (Zander, 2003). Gobies have an important role in the ecosystem as they are secondary consumers and preys for larger fish (Arntz, 1974), sea birds (Doornbos, 1984) or seals (Sievers, 1989). They serve as vectors of parasites to commercial fishes such as cod (*Gadus morhua* Linnaeus, 1758), plaice (*Pleuronectes platessa* Linnaeus, 1758), or bass (*Dicentrarchus labrax* (Linnaeus, 1758)) (Zander, 2011). Parasites of these economically important fishes are well studied (e.g., Hemmingsen & MacKenzie, 2001; MacKenzie et al., 1970) unlike parasites of gobies, even though goby species play an important role in transmitting parasites (Zander, 1998a).

Published works about parasitation of European marine gobies are scattered and usually are focused on a single parasite species or group (e.g., Køie et al., 2004; Raibaut et al., 1998). There are only several complex works on parasitation of European marine gobies, focussing on a whole goby and parasite community (Zander et al., 1999; Zander, 2004). Ways of infection by parasites in marine environment are shown in Fig. 1.

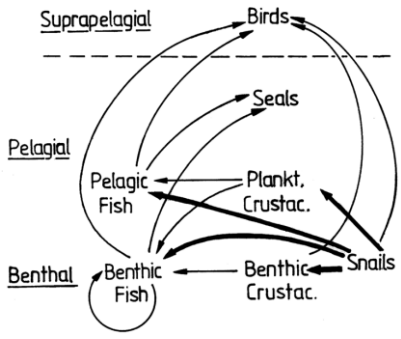

Fig. 1.Ways of infection by parasites in the marine environment, taken from Zander (1993).

The aim of this work is to review works on parasitation of gobies from European marine waters. This is put into context considering the parasites' impacts on the fish, including the physiology, immunology, fitness, mortality and behaviour of the fish.

2 Life of gobies

Gobies start their life as planktonic larvae in the summer. Larvae are fully developed for feeding on plankton right after hatching. They have a functional mouth and an anus and they are able to swim due to developed pectoral fins. Due to their small size and their planktonic way of life, goby larvae feed mostly on copepod nauplia (Fonds, 1970). The duration of a larval phase differs for every species, but generally they are known to have a relatively long larval life. In European gobies it can vary from 13 days in *Zosterisessor ophiocephalus* (Pallas, 1814) to 35 days in *Gobius cobitis* Pallas, 1814 (Gonçalves, 2006). The benthic gobies move to the bottom in autumn, whereas hyperbenthic and nektonic species remain in pelagic zone. In the following year they reproduce between spring and summer and die afterwards. The exceptions are some longer living species among which, for example G*obius paganellus* Linnaeus, 1758, that can live up to ten years (Miller, 1961).

2.1 Ways of infection and feeding habits of gobies

Gobies are mainly predators, feeding on invertebrates, as well as on fishes. Sometimes they function as auchwus feeders, eating plants as well as sessile animals (polychaetes, sponges) (Zander, 2011). Feeding habits of gobies are essential in this review, because more than 60 % of parasites infect gobies via their prey (Zander, 2004). In planktonic and benthic feeders, there is a rather different composition of parasites. Planktonic calanoid copepods, which are the main source of food for larvae, hyperbenthic and nektonic fishes, encompass more hemiurid digeneans and cestodes than the benthic prey (Zander, 2004). On the other hand, benthic feeders harbour more parasites, which get to the host by active penetration than by food (Zander, 2003). Benthic gobies prey on various benthic invertebrates, especially isopods and amphipods which are intermediate hosts of the digenean *P. atomon*, nematodan *Hysterothylacium* sp., acanthocephalan *Echinorhynchus gadi*, etc. (Zander, 2004). Polychaetes, as another benthic prey, are a source of a digenean *Asymphylodora demeli* Markowski, 1935 and other parasites (Zander, 2004).

From a parasitic composition of the intestine of gobies it is possible to deduce their life style, in context of their feeding habits. A presence of excysted metacercariae and progenetic adults of a digenean belonging to *Timoniella* in the gut of *Pomatoschistus microps* (Krøyer, 1838) and excysted metacercariae of the digenean *Bucephalus baeri* Maillard, 1976 in the gut of *Pomatoschistus minutus* (Pallas, 1770) (Malek, 2003) can point to cannibalistic behaviour of the fish, because metacercariae of these digeneans have been found in the muscles of other gobies (Malek, 1997). Scavenging behaviour of gobies can be deduced from the presence of the progenetic adult of a digenean *Prosorhynchoides*

gracilensis (Rudolphi, 1819) in the gut of *P. microps* and *P. minutus* (Malek, 2003). As metacercariae of *P. gracilensis* are specific to the brain and spinal nerves of gadoid fishes (Matthews, 1974), gobies might acquire them by feeding on a dead fish. This parasite appears as progenetic adult in the gut of gobies, because it cannot properly evolve in the goby host, being specific to gadoid fish.

3 Main metazoan parasite groups

The seven main metazoan groups of parasites found in gobies are: Myxozoa, Monogenea, Digenea, Cestoda, Acanthocephala, Nematoda and Crustacea. Gobies also harbour protozoan parasites (e.g., *Haemogregarina* sp. Danilewsky, 1885 (Apicomplexa, Conoidiasida), *Eimeria variabilis* (Thélohan, 1893) (Apicomplexa, Coccidia (Abollo et al., 1998)), as well as bacteria and viruses, but they fall outside of the scope of this thesis. Those seven metazoan groups are introduced with a description of their morphology, life cycles, infection sites and effects on their hosts.

3.1 Myxozoa

Myxozoa is a phylum of metazoan parasites which form spores, which are transformed into spore shell valves, amoeboid infective germs and polar capsules with extrudable filaments. These filaments are not used for injecting an infective sporoplasm, but for the attachment to the host cell. Myxozoans have been long considered Protozoa, but the multicellular differentiation of their cells and molecular works disproves this theory (Schlegel et al., 1996). They are related to Cnidaria (Nesnidal et al., 2013). The diversity and life cycles of myxozoans are not well studied yet. Around 2,000 species belonging to this phylum are known (Marianne Køie, 2003). One of the most species-rich genus, *Myxobolus*, comprises approximately 800 species described to date (Eiras et al., 2005), but the complete life cycle has been uncovered for only 14 of them (Picon-Camacho et al., 2009). Only 30 *Myxobolus* species have been so far found in marine fishes, especially in estuaries; the others are considered to occur in freshwater systems (Picon-Camacho, 2009). Interestingly, although so few species are so far known from the marine environment, this phylum originated in the sea, from where it established four times independently in freshwaters during the evolution (Picon-Camacho et al., 2009). Currently, more and more species are being described (Mackenzie & Kalavati, 2014), but just a little is still known about this interesting phylum.

Myxozoans are rather specialists in terms of their hosts (Picon-Camacho et al., 2009). The life cycle of some species consists of an actinosporean stage in invertebrates (mostly in Polychaeta in the marine environment) and of a myxosporean stage in a fish. In the past, the myxosporean and the actinosporean stages were considered as totally different phyla (Mackenzie & Kalavati, 2014). Generally, it is considered that actinospores float in the water, and after a direct contact with the fish they penetrate into its tissues (Volf & Horák, 2007). However, according to Køie (2003), it is possible that they can enter a fish host by its alimentary tract and it is still not known which of these ways (or

both) is the right one. In the marine environment, a direct fish to fish transmission has also been described (Diamant, 1997; Yasuda et al., 2002). According to (Mackenzie & Kalavati, 2014) only six marine species have been described to date to have a complete two-host life cycle; in all cases the intermediate host was a Polychaeta species. *Ellipsomyxa gobii* Køie, 2003 was the first described marine myxozoan with the uncovered two-host life cycle (Køie et al., 2004). Its actinosporean stage is found in *Nereis* spp. (Polychaeta, Nereidae) and the myxosporean stage parasitize on *P. microps* (Gobiidae, Perciformes) (Køie et al., 2004).

By 2009, twelve myxozoan species have been found in gobies (Picon-Camacho et al., 2009). Those infecting European marine gobies are listed in Table 1. They can be found in the gall-bladder (*Ceratomyxa* sp. (Abollo et al., 1998)), hepatic and bile gut (*E. gobii* (Marianne Køie, 2003)), gill cartilage (*Myxobollus albi* Picon-Camacho, Holzer, Freeman, Morris & Shinn, 2009 (Picon-Camacho et al., 2009)) and muscle tissues (*Kudoa camarguensis* Pampoulie, Marques, Crivelli & Bouchereau, 1999, *Kudoa nova* Naidenova, 1975 (Pampoulie et al., 2001; Pascual et al., 2012)). Some myxozoan species have been reported as pathogens of marine fishes (Kabata & Whitaker, 1985; Sindermann, 1957) and some species serve as spoilage agents of the fish. They produce macroscopic cysts in the flesh of the host and also cause the post-mortem myoliquefaction (Mackenzie & Kalavati, 2014). These processes can result in considerable economic losses (Henning et al., 2013). As an example, *K. camarguensis*, living in the muscle tissue of gobies *P. microps* and *P. minutus* causes liquefaction of the tissue in less than one hour after a host´s death (Pampoulie et al., 1998). Myxozoan parasites may have effect on a fish host fecundity and survival (Adlerstein & Dorn, 1998), but this has not been reported for gobies so far.

Table 1. Myxozoan parasites found on gobies and their goby hosts.

Hosts are written with the abbreviation of the sea (in parenthesis): M: Mediterranean, N: North Sea, Az: Azov Sea

References: 1: (Pampoulie et al. , 1999), 2: (Pampoulie et al., 2001), 3: (Pampoulie, 2002), 4: (Køie, 2003), 5: (Køie et al., 2004), 6: (Picon-Camacho et al., 2009), 7: (Pascual et al., 2012), 8: (Abollo et al., 1998)

parasite	host	references
Kudoa camarguensis Pampoulie, Marques, Crivelli & Bouchereau, 1999	*P. microps* (M), *P. minutus* (M)	1, 2, 3
Ellipsomyxa gobii Køie, 2003	*P. microps* (N)	4, 5
Myxobolus albi Picon-Camacho, Holzer, Freeman, Morris & Shinn, 2009	*P. microps* (N)	6
Kudoa nova Naidenova, 1975	*Neogobius melanostomus* (Az)	7
Ceratomyxa sp. Thélohan, 1892	*G. paganellus* (A)	8

3.2 Monogenea

Monogenea is a class of ectoparasitic flatworms. They possess special hooks, glands and/or suckers for attachment. Monogeneans are hermaphrodites and they usually have just one host during the whole lifespan. Ectoparasitic monogeneans feed on the mucus and skin of infected fishes and cause cutaneous damage that can be prone to secondary infections (Roberts, 2012). Gobies are not a really suitable hosts for Monogenea, because their skin and gills are abundantly covered by mucus, which makes it more difficult for ectoparasites to attach (Sasal et al., 1998). Nevertheless, 18 monogenean species were reported from the European marine gobies so far (see Tab. 2; Harris et al., 2004; Huyse et al., 2006; Huyse et al., 2004).

The most abundant genus of monogeneans in gobies as well as in many other fishes is *Gyrodactylus*. Its representatives, both as specialists and generalists, parasitize on 19 orders of bony fishes (Huyse & Volckaert, 2005), in fresh-, as well as in marine waters. Species of *Gyrodactylus* have a remarkable mode of reproduction (Huyse & Volckaert, 2005). After birth, there is already a grown embryo in uterus and later, in adulthood a new embryo begins to grow inside it. This "Russian doll" model system is called hyperviviparity and together with a short generation time and the alteration of asexual, parthenogenethic and sexual reproduction, contributes to an explosive reproduction just on one host (Huyse & Volckaert, 2005). It can produce a liveable daughter 24 hours after a parent's birth (Cable & Harris, 2002). Due to its fast reproduction, *Gyrodactylus* can represent a serious thread for fish aquacultures (Huyse & Volckaert, 2005). This species-rich genus has 409 species recognised by 2004 (Harris et al., 2004). According to Huyse et al. (2003), species parasitizing gobies can be divided into two groups. The monofyletic and host-specific group A belongs to the subgenus G. (*Mesonephrotus*) and is usually found on gills, whereas representatives of the group B, classified in the subgenus G. (*Paranethropus*), is found on fins and skin of fishes and have a lower host specificity (Huyse & Volckaert, 2005). Species of *Gyrodactylus* are morphologically identified mainly using the hard parts of the posterior attachment organ (Malmberg, 1970) and a shape of copulation organs (Sasal et al., 1998).

Gyrodactylus can be very specific to its host and sympatric speciation and speciation by host-switching may occur (Brooks et al., 1993). Their viviparous reproduction and the ability of switching hosts as an adult is considered as a principal feature promoting specialisation (Vanhove & Huyse, 2015). This parasite is capable of surviving for some time without its host and its "swimming behaviour" has been described as well (Cable et al., 2002). Some species can tolerate a wide range of salinity and temperature. For example, *Gyrodactylus rugiensis* Gläser, 1974 was found in the oligohaline zone of western Baltic Sea, in the intertidal zone of the Atlantic Sea near Northern France (salinity 0-33 ‰) and in fully marine areas at the Belgian Atlantic coast (Vanhove & Huyse, 2015). Due to these abilities *Gyrodactylus* spp. can easily invade new areas.

Table 2. Monogenean parasites found in gobies and their goby hosts.

Hosts are written with the abbreviation of the sea (in parenthesis): B: Baltic Sea, N: North Sea, Nw: Norwegian Sea, A: Atlantic Ocean, M: Mediterranean, Ad: Adriatic Sea, Bl: Black Sea

References: 1: (Huyse et al., 2004), 2: (Huyse et al., 2006), 3: (Geets et al., 1998), 4: (Harris et al., 2004), 5: (Longshaw et al. , 2003), 6: (Huyse & Volckaert, 2002), 7: (Huyse & Volckaert, 2005), 8: (Huyse et al., 2003), 9: (Vanhove & Huyse, 2015), 10: (Huyse, 2002), 11: (Sasal et al., 1998), 12: (Vanhove et al., 2014), 13: (Kvach & Oğuz, 2009)

Monogenean parasite	host	references
Gyrodactylus rugiensis Gläser, 1974	*P. microps* (B, N, A, M), *P. minutus* (B)	2, 4, 6, 7, 8, 10,
G. rugiensoides Huyse & Volkaert, 2002	*P. minutus* (B, N, M), *P. lozanoi* (N), *P. pictus* (N)	2, 6, 7, 8, 12
G. ostendicus Huyse & Malmberg, 2004)	*P. microps* (B, N, M), *Po. marmoratus* (B, M, Ad), *K. panizzae* (Ad)	2, 12
G. branchialis Huyse, Malmberg & Volckaert, 2004	*P. microps* (B, N, M), *Po. marmoratus* (B, M, Ad), *P. minutus* (B, M)	1, 2, 12
G. arcuatus Bychowsky, 1993	*K. panizzae* (Ad), *G. flavescens*, *Po.*	2, 4
G. gondae Huyse, Malmberg & Volckaert, 2004	*P. minutus* (B, N, Nw, M), *P. lozanoi* (N)	1, 2, 7, 12
G. flavescensis Huyse, Malmberg & Volckaert, 2004	*G. flavescens* (N, Nw)	1
G. arcuatoides Huyse, Malmberg & Volckaert, 2004	*P. pictus* (N)	1
G. longidactylus Geets et al., 1998	*P. lozanoi* (N)	3, 7, 9, 10
G. cf. *longidactylus* Huyse et al., 2003	*P. norvegicus* (N)	7, 8
G. flesi Malmberg, 1957	*N. melanostomus*, *G. niger*	4
G. micropsi Gläser, 1974	*P. microps* (N), *P. minutus* (N), *P. lozanoi* (N)	4, 6, 7, 8, 10
G. cf. *micropsi* Huyse et al., 2003	*P. minutus* (N), *P. lozanoi* (N)	7, 8
G. cf. micropsi 2 Huyse et al., 2003	*P. minutus* (N), *P. lozanoi* (N)	7, 8
G. proterorhini Ergens, 1967	*P. marmoratus*, *Z. ophiocephalus*, *G. cobitis*, *G. niger*, *N. melanostomus*	4
G. quadratidigitus Longshaw, Pursglove & Shinn, 2003	*Thorogobius epphippiatus* (A)	5, 12
G. niger sp. Huyse et al., 2003	*G. niger* (N)	8
Haliotrema cupensis Sasal, Paget & Euzet, 1998	*G. cobitis* (M)	11

A geographic distribution of *Gyrodactylus* spp. depends mainly on the distribution of its host species and the more closely related the hosts are, more closely related its parasites are (Vanhove et al., in press). Gobies *P. minutus* and *Pomatoschistus lozanoi* (de Buen, 1923) are sympatric species which

are able to hybridize with each other (Wallis & Beardmore, 1980). Their close genetic relationship is supported by the fact that they share several species of *Gyrodactylus* spp. (i.e., *Gyrodactylus gondae* Huyse, Malmberg & Volckaert, 2004, *Gyrodactylus rugiensoides* Huyse & Volkaert, 2002, *Gyrodactylus* cf. *micropsi* Huyse et al., 2003 (Huyse & Volckaert, 2005)). *Pomatoschistus norvegicus* (Collett, 1902) is also closely related to the aforementioned *Pomatoschistus* species, but it does not harbour *G. gondae* (neither the remaining mentioned *Gyrodactylus* species). It is not clear if this parasite is specific to the two first mentioned hosts, or it just did not have the opportunity to colonize *P. norvegicus*. This can be partly explained by the fact that this goby is ecologically slightly different from the other two gobies: it lives in a deeper sections of the continental shelf, down to 200 m (Miller, 1986). On the other hand, it hosts a similar species to *G. longidactylus* Geets et al., 1998 (which is uniquely harboured by *P. lozanoi*), assigned to *G.* cf. *longidactylus* Huyse et al., 2003 (Huyse & Volckaert, 2005). Moreover, although *P. minutus* and *P. lozanoi* are sympatric species, *P. minutus* does not harbour *G. longidactylus* (Geets et al., 1998). This proves that host-switching does not occur whenever it is possible.

Host-parasite relationship in *Gyrodactylus* genus is usually a combination of a co-evolution and host-switching. Host-switching happens more easily on the gregarious type of fishes, whereas co-specialization occurs rather on fishes with an asocial life style (Huyse & Volckaert, 2005). Most goby species do not live very closely together, but events of host-switching occur as well (Huyse & Volckaert, 2005)

3.3 Digenea

These endoparasitic flukes belong to the phylum Platyhelminthes, class Trematoda. Digeneans have complex life cycles with several larval stages and a variety of intermediate hosts. They use both sexual and asexual reproduction. The asexual reproduction takes place in molluscs, the sexual one in all classes of marine vertebrates and metacercariae can be found in many groups of invertebrates and vertebrates (Rohde, 2005). Digeneans are the most abundant parasites in gobies (Boonyaratpalin, 1981; Claridge et al. 1985; Gharbawi, 1994; Koter, 1962; Markowski, 1935, 1966; Petersen, 1992; Soliman, 1996; Zander et al., 1984; Zander, 1993).

Digenea vary in the size; they can have from 250 μm to over 10 cm in length (Rohde, 2005). Most of them have an oral sucker, which is connected with a mouth, and a ventral one, which they use only to attach (although in some groups both suckers are missing). Most of the body cavity is usually filled with the reproductive system. With a few exceptions (Schistosomatidae and some Didymozoidae), digeneans are hermaphrodites (Rohde, 2005).

The life cycle of a digenean begins when an adult produces eggs that are released to the environment. They usually hatch and a short-lived, ciliated and non-feeding larva, called miracidium,

is released. The miracidium swims in the water and penetrates a mollusc, its first intermediate host. Inside a mollusc, it loses its ciliated epithelial cells and evolves into a mother sporocyst. The sporocyst is actually an adult reproducing asexually, and it is fed directly through the tegument. The mother sporocyst can produce daughter sporoctysts or rediae. Both these stages can reproduce again, as well as the mother sporoctyst can, thus, on this way they use the maximum space of a mollusc. All these stages live in the haemocoel of their host. Sporocysts and rediae can also produce cercariae, a stage that can leave the mollusc and continue to second intermediate, or final host. In the second intermediate host cercariae transform into metacercariae and in the final host evolve into adults. Gobies usually serve as second intermediate hosts (e.g., for *Bucephalus minimus* (Stossich, 1887) and *C. concavum* (Malek, 2001)), although they can be final (e.g., for *Aphalloides coelomicola* Dollfus, Chabaud & Golvan, 1957 (Vaes, 1978) and *Aphalloides timmi* (Zander, 1998a)) as well paratenic hosts. An example of a digenean life cycle can be seen in Figure 2 and a list of Digenea species found in marine European gobies in Table 3.

The transmission of parasites into gobies can be by two ways. The metacercarie can be eaten, and then they either continue into a gut or stay in the body cavity (e.g., Hemiuroidea), or they actively penetrate into a second intermediate host (e.g., members of Bucephaloidea, Diplostomoidea, Opisthorchioidea and Xiphidiata) (Rohde, 2005). The second way of transmission is the most common in digeneans, for which special penetration glands are evolved.

After the goby, digeneans usually need to get into a bigger fish or a bird, therefore they need to increase the chances of getting consumed. It is assumed that a high infestation of metacercariae (for example of *C. concavum*, or *Cryptocotyle lingua* (Creplin, 1825)) in the skin and fins (especially pectoral fins) of a goby, restricts its mobility, which makes a goby easier prey for a fish predator (Zander et al., 1999). This is an example of an effect of parasite on behaviour of its host.

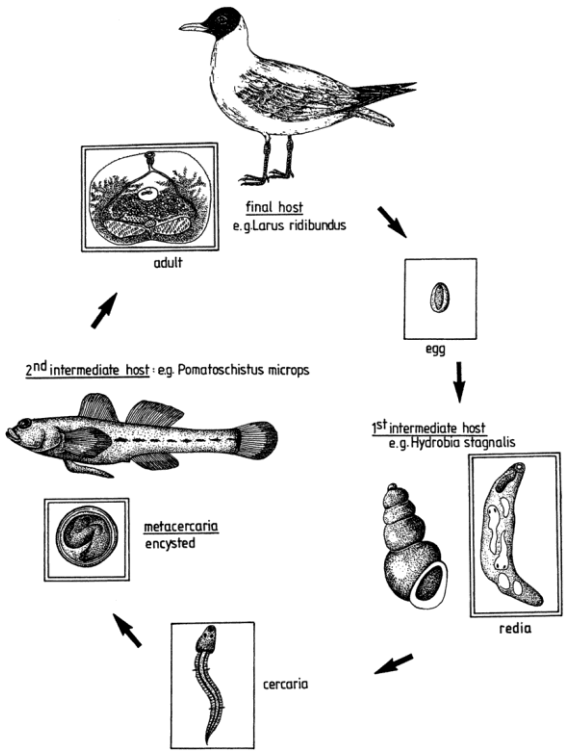

Fig. 2. A life cycle of digenean *Cryptocotyle concavum* with its most frequent host *P. microps*, taken from Zander et al. (1984).

Digeneans can infect various microhabitats on gobies, such as intestine, liver, muscles, body cavity, dermis, fins, kidney, gill chamber, eye or brain (Zander, 2004). In many cases, the digenean infection is asymptomatic and it does not pathogenically affect its goby host (Rohde, 2005), although sometimes the consequences are rather significant, as in the mentioned case of alteration of the goby behaviour, making it an easy prey. Another example of a serious consequence on a goby host is, according to Shchepkina (1981), the case of *C. concavum*, which reduces the total amount of lipids in the skin and muscles of *Neogobius melanostomus* (Pallas, 1814); this has an effect on its body condition.

Parasitation of digeneans *Bucephalus minimus* and *Cryptocotyle concavum* on sand-gobies *P. microps* and *P. minutus* reduces their hepatosomatic index (Malek, 2001). There are two possible explanations of this phenomenon: 1) parasites mechanically damage liver cells and therefore the weight of the liver is reduced (Malek, 2001); 2) metacercarial cyst walls accumulate, store and neutralize their own waste (Benjamin & James, 1987), therefore they can accumulate and neutralize host waste material, which results in a reduced need of an extensive liver activity (Malek, 2001). Digenean parasites can also influence the endocrine system of their hosts (Read et al., 1990), which was proven by the reduction of a gonadosomatic index in *P. minutus* (Malek, 2001).

Table 3. Digenean parasites found in gobies and their goby hosts.

Hosts are written with the abbreviation of the sea (in parenthesis): B: Baltic Sea, N: North Sea, Bl: Black Sea, A: Atlantic, M: Mediterranean, Az: Azov Sea

1: (Zander, 2004), 2: (Zander et al., 1999), 3: (Kvach, 2002), 4: (Malek, 2004), 5: (Kvach & Oğuz, 2009), 6: (Sasal et al., 1996), 7: (Kvach & Winkler, 2011), 8: (Kvach, 2010), 9: (Kvach, 2007), 10: (Kvach, 2004), 11: (Malek, 2001), 12: (Vaes, 1978), 13: (Pampoulie, et al., 1999), 14: (Abollo et al., 1998), 15: (Freitas et al., 2009), 16: (Sey, 1970b, 1970b), 17: (Bartoli et al., 2005), 18: (Kvach & Skóra, 2007), 19: (Zander, 2003), 20: (Naidenova, 1970), 21: (Zander, 1998a)

parasite	host	references
Cryptocotyle concavum (Creplin, 1825) Lühe, 1899	*P. microps* (B, A), *P. minutus* (B, A), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B), *N. melanostomus* (Bl), *Neogobius ratan* (Bl) (Nordmann, 1840), *Neogobius fluviatilis* (Bl) (Pallas, 1814), *Z. ophiocephalus* (Bl), *Proterorhinus marmoratus* (Bl) (Pallas, 1814), *Pomatoschistus marmoratus* (Bl) (Risso, 1810), *Ponticola eurycephalus* (Bl) (Kessler, 1874) , *Mesogobius batrachocephalus* (Bl) (Pallas, 1814) , *Neogobius gymnotrachelus* (Bl) (Kessler, 1857)	1, 3, 4, 5, 8, 9, 10, 11, 18
C. lingua (Creplin, 1825)	*P. microps* (B, N, A), *P. minutus* (B, A), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B), *N. melanostomus* (Bl), *N. ratan* (Bl), *N. fluviatilias* (Bl), *P. marmoratus* (Bl), *Po. marmoratus* (Bl), *N. eurycephalus* (Bl), *M. batrachocephalus* (Bl), *Ponticola syrman* (Bl) (Nordmann, 1840)	1, 2, 3, 4, 5, 8, 9, 10, 19
C. jejuna (Nicoll, 1907)	*P. microps* (A)	4
Cryptocotyle sp. Lühe, 1899	*P. microps* (A)	15
Apatemon gracilis Rudolphi, 1819	*P. microps* (B), *P. minutus* (B), *G. flavescens* (B), *G. niger* (B), *P. pictus* (B)	1, 19
Acanthostomum balthicum Reimer, Hildebrand, Scharberth & Walter, 1996	*P. microps* (B), *P. minutus* (B), *P. pictus* (B), *G. niger* (B)	1, 19
Podocotyle atomon (Rudolphi, 1802)	*P. minutus* (B, N, A), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B), *P. microps* (A, B), *Gobius geniporus* (Ad) Valenciennes, 1837	1, 4, 16, 19
Macvicaria alacris (Looss, 1901) Gibson & Bray, 1982	*P. minutus* (B), *G. flavescens* (B)	1
Aphalloides timmi Reimer, 1970	*P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *P. microps* (B)	1, 19

Aphalloides coelomicola Dollfus, Chabaud & Golvan, 1957	*Po. marmoratus* (Bl), *P. microps* (M)	8, 12, 13
Asymphylodora demeli Markowski, 1935	*P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B), *P. microps* (B), *N. syrman* (AZ), *N. melanostomus* (Az)	1, 19, 20
A. pontica Chernyshenko, 1949	*N. melanostomus* (Bl), *Po marmoratus* (Bl)	3, 8, 9
Brachyphallus crenatus (Rudolphi, 1802)	*P. minutus* (B), *G. niger* (B), *P. microps* (B)	1, 19
Derogenes sp. Lühe, 1900	*G. bucchichi* (M)	6
Derogenes varicus (Müller, 1784)	*P. pictus* (B), P. minutus (B)	1, 19
Hemiurus communis Odhner, 1905	*P. minutus* (B), *G. flavescens* (B), *G. niger* (B), *P. pictus* (B), *P. microps* (B)	1, 19
Lecithaster confusus Odhner, 1905	*G. flavescens* (B), *G. niger* (B), *P. pictus* (B)	1, 19
L. gibbosus Rudolphi, 1802	*P. minutus* (B, A), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B), *P. microps* (B)	1, 4, 19
Magnibursatus caudofilamentosa (Reimer, 1971)	*P. minutus* (B), *P. microps* (B)	1, 19
Diplostomum spathaceum (Rudolphi, 1819)	*P. microps* (B), *P. minutus* (B), *N. melanostomus* (B)	1, 7, 18, 19
Tylodelphys sp. Diesing, 1850	*N. melanostomus* (B)	7
Tylodelphys podicipina Kozicka & Niewiadomska, 1960	*P. microps* (B), *P. minutus* (B), *P. pictus* (B)	1, 19
Tylodelphys clavata (von Nordmann, 1832)	*N. melanostomus* (B)	18
Cardiocephaloides longicollis (Rudolphi, 1819) Dubois, 1982	*P. microps* (B), *P. minutus* (B), *G. niger* (B)	1, 2, 19
Microphallidae Ward, 1901	*P. microps* (B), *P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B)	1, 18
Bunocotyle cingulata Odhner, 1928	*G. flavescens* (B)	2
Prosorhynchoides gracilescens (Rudolphi, 1819)	*P. microps* (A), *P. minutus* (A)	4
Pygidiopsis genata Looss, 1907	*N. melanostomus* (Bl), *N. fluviatilis* (Bl), *P. marmoratus* (Bl), *Po. marmoratus* (Bl), *P. eurycephalus* (Bl)	3, 5, 9
Bucephalus baeri Maillard, 1976	*P. minutus* (A)	4
Bucephalus polymorphus von Baer, 1827	*N. melanostomus* (B, Bl), *N. ratan* (Bl)	7, 10
Bucephalus minimus (Stossich, 1887)	*P. microps* (A), *P. minutus* (A)	4, 11

Timoniella spp. Rebecq, 1960	*P. microps* (A), *P. minutus* (A)	4
Timoniella imbutiforme (Molin, 1859)	*P. marmoratus* (Bl), *Po marmoratus* (Bl), *N. melanostomus* (Bl), Z. *ophiocephalus* (Bl), *N. melanostomus* (Bl)	5, 9, 3
Paratimonia gobii Prévôt & Bartoli, 1967	*P. minutus* (A), *Po marmoratus* (Bl)	4, 8
Magnibursatus skrjabini (Vlasenko, 1931)	*P. marmoratus* (Bl)	5
Nicolla skrjabini (Iwanitzky, 1928)	*N. fluviatilis* (Bl), *N. kessleri* (Bl) (Günther, 1861) , *N. ratan* (Bl)	10
Deretrema scorpaenicola Bartoli & Bray, 1990	*G. bucchichi* (M)	6
Helicometra sp. Odhner, 1902	*G. bucchichi* (M)	6
Helicometra fasciata (Rudolphi, 1819)	*G. paganellus (*A), *G. cobitis* (Ad), *G. niger* (Ad)	14, 16
Lecithochirium furcolabiatum (Jones, 1933)	*G. paganellus* (A)	14
Lecithochirium musculus (Looss, 1907)	*P. microps* (A), *G. cruentatus* (Ad)	15, 16
Lecithochirium grandiporum (Rudolphi, 1819)	*G. cruentatus* (Ad)	16
Cainocreadium sp. Nicoll, 1902	*G. paganellus* (A)	14
Prosorhynchus sp. Odhner, 1905	*P. microps* (A)	15
Prosorhynchoides tergestinus (Stossich, 1883)	*G. niger* (Ad), *G. geniporus* (Ad)	17
Zoogonoides viviparus (Olsson, 1868)	*P. pictus* (B), *P. microps* (B)	19
Pronoprymna petrowi (Layman, 1937)	*Neogobius melanostomus* (Az)	20
Bacciger grandispinatus Naidenova, 1970	*Mesogobius batrachocephalus* (Az)	20
Microphallus claviformis (Brandes, 1888)	*P. microps* (B)	21

The digenean *Aphalloides coelomicola* is a special case among digeneans, because it needs a death of its host to be able to continue its life cycle. The metacercariae penetrate into *P. microps*, the typical final host. After penetrating, they migrate into the abdominal cavity of the fish and evolve into adults. *A. coelomicola* cannot release its eggs out of the host's body cavity, so it needs to wait for the host death or to provoke it (Maillard, 1973). A co-occurence of this parasite and *Kudoa camarguensis* (Myxozoa) has been observed (Pampoulie & Morand, 2002). *Kudoa* causes liquefaction of tissues of a host in less than one hour after host's death (Pampoulie, et al., 1999), which facilitates *A. coelomicola*

to release its eggs. Infection by *A. coelomicolla* has also an indirect impact on a host, as it influences its reproductive effort and can cause gonadal regression after the overcome of a certain parasite load (Pampoulie et al., 1999).

There is a case of adaptive relationship between a digenean *Cryptocotyle concavum* and a goby *P. microps* in the Baltic Sea, in which this parasite is specifically located in its kidneys (Zander et al., 1984, 1999; Zander, 1998), whereas in other goby hosts it occupies fins and skin (Zander et al., 1984). This special habitat allows the parasite an enormous reproduction. Kidneys offer a lot of space, therefore *C. concavum* can accumulate as much as 2,000 cysts (Zander & Kesting, 1996). This adaptation could probably lead to a specialisation (Zander, 1998a).

3.4 Cestoda

Cestoda also belongs to the phylum Platyhelminthes, but there are less species of cestodes than of digeneans found in gobies. Moreover, there are only several works that mention cestodes in European marine gobies as members of studied parasite community (e.g., Kvach, 2004; Malek, 2004), and works focused on Cestoda parasites in European marine gobies are lacking.

Adult cestodes live in the digestive tract of gobies and other vertebrates. They do not have the digestive system, so they absorb nutrients through the outer layer of the body (the neodermis). Cestodes are divided into two major groups: the Cestodaria, which includes the orders Gyrocotylidea and Amphilinidea, and the Eucestoda (the real tapeworms) comprising of the remaining eleven cestode orders (Rohde, 2005). According to the published literature, cestode parasites of gobies mainly belong to Eucestoda (Kvach, 2004; Malek, 2004; Zander, 2004). Cestode parasites found in European marine gobies are listed in Table 4.

The eucestodes have an anterior holdfast organ called scolex, whose shape is used for determination of orders. Their ribbon-like body is called strobila and it is subdivided into a linear series of compartments (proglottids). In every proglottid, there are one or more sets of reproductive organs; this makes eucestodes polyzoic (Rohde, 2005).

The life cycle of Cestoda is usually closely linked to the life of its host, but little is known about life cycles of the marine cestodes. Usually they have one or more intermediate hosts and a final host. The life of eucestodes begins as a hexacanth embryo. In pseudophyllideans and some trypanorhynchs, the embryo is surrounded by a ciliated membrane. It hatches from the egg and becomes a free-living stage, known as coracidium. The coracidium later passes through two parasitic stages: the procercoid, which is found mainly in crustaceans, and the plerocercoid parasitizing on vertebrates. The hexacanths of most marine eucestodes do not have cilia and remain inside the egg until the appropriate intermediate host consumes them (Rohde, 2005). The way of transmission of

cestodes to gobies is usually by consuming crustaceans. Gobies can sometimes serve as final host, but mostly as intermediate, or paratenic hosts (Groot, 1971; Robert et al., 1988; Zander et. al., 2000).

Among the most often cestodes parasiting Gobiidae belong *Schistocephalus solidus* (Zander 2004) and *Proteocephalum gobiorum* Dogiel & Bychowsky 1939 (Kvach & Oğuz, 2009). Cestodes can parasitize gobies as a larval stage as well as an adult, and can be found in their intestine and a body cavity.

Table 4. Cestodes found in Gobies and their goby hosts.

Hosts are written with the abbreviation of the sea (in parenthesis): B: Baltic Sea, Bl: Black Sea, A: Atlantic

References: 1: (Zander et al., 1999), (Zander, 2004), 3: (Zander, 2005a), 4: (Kvach & Oğuz, 2009), 5: (Kvach, 2002), 6: (Kvach & Skóra, 2007), 7: (Kvach & Winkler, 2011), 8: (Kvach, 2004), 9: (Freitas et al., 2009), 10: (Malek, 2004), 11: (Zander, 2003)

parasite	host	references
Schistocephalus solidus (Müller, 1776)	*G. niger* (B), *P. minutus* (B), *P. microps* (B), *P. pictus* (B), *G. flavescens* (B), G. niger (B)	1, 2, 11
Proteocephalus sp. Weinland 1858	*G. flavescens* (Bl), *N. syrman* (Bl), *N. gymnotrachelus* (Bl), *P. minutus* (A)	3, 8, 10
Proteocephalus percae (Müller, 1780)	*G. niger* (B), *P. microps* (B), *P. minutus* (B)	1, 2, 11
Proteocephalus gobiorum Dogiel & Bychowsky 1939	*P. marmoratus* (Bl), *N. fluviatilis* (Bl), *Z. ophiocephalus* (Bl), *N. melanostomus* (Bl)	4, 5, 8
Ligula sp. Bloch, 1782	*G. niger* (B), *G. flavescens* (B)	2, 11
Ligula pavlovskii Dubinina, 1959	*G. flavescens* (B), *N. fluviatilis* (Bl)	3, 8
Ligula intestinalis (Linnaeus, 1758)	*P. microps* (A), *P. minutus* (A)	10
Bothriocephalus sp. Rudolphi,1808	*P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *N. melanostomus* (B), *P. microps* (B)	2, 6, 11
Bothriocephalus scorpii (Müller, 1776)	*G. flavescens* (B), *N. melanostomus* (B), *P. minutus* (A)	3, 7, 10
Acanthobothrium sp. van Beneden, 1850	*P. microps* (A), *P. minutus* (A)	10
Echeneibothrium sp. van Beneden, 1849	*P. microps* (A), *P. minutus* (A)	10
Tetraphyllidea	*P. microps* (A)	9

The effects of cestodes on gobies have not been reported yet, hence some effects on other fish species will be mentioned. The pathogenesis is usually correlated with the scolex morphology and the number of individuals present. The scolex can cause changes in mucosa and layers of the intestinal wall, for

example: fibrosis or loss of epithelium around the site of attachment, focal pressure necrosis, hyperplasia and metaplasia of mucosa and hemorrhagia (Fujita et al., 1991). *Schistocephalus solidus* (Cestoda: Pseudophyllidea) parasitizing *Gasterosteus aculeatus* Linnaeus, 1758 (Gasterosteidae, Actinopterygii) increases handling time for a large prey, therefore the fish starts to search for smaller prey (Barber & Huntingford, 1995). This alteration of behaviour can affect gobies as well, because they also harbour this parasite species. This shows that cestode infection can have various effects on the fish. An addition, cestodes can function as bioindicators, as they are very efficient in accumulating heavy metals in their tissues (Taraschewski & Sures, 1996).

3.5 Acanthocephala

Acanthocephala, the "thorny headed worms" belong, together with the Rotifera, to the phylum Syndermata (Lasek-Nesselquist, 2012). They have a pseudocoel and a cylindrical body of white or creamy colour. The body is divided into an anterior part (presoma) and the posterior part (metasoma). The presoma consists of a proboscis and a neck and is usually inserted in the intestinal wall of the host. The metasoma comprises of a trunk of the animal with reproductive organs and it lies inside the intestinal lumen of the host. Some acanthocephalan species change a place of their attachment in the host time to time; these species do not perforate the intestine of the host (e.g. *Moniliformis moniliformis* Meyer, 1933) (Rohde, 2005). The other species attach permanently to one place in the intestine wall of the host. They invade deep layers of the wall, so they can even perforate it, like, e.g., *Pomporhynchus laevis* (Rohde, 2005). Interior part of the proboscis cavity moves by specialized muscles, whereas its outer part is moved by a hydraulic pressure from lemnisci (a pair of sacks in presoma) and a lacunar system (canals, which may function as a circular system). Acanthocephalans do not have an intestine. They absorb nutrients through the tegument, which is formed by syncytium. Acanthocephalans are gonochorists with a sexual dimorphism. It means that one individual has just one type of reproductive organs and that female and male look differently. Embryonated eggs are released into the host's intestinal lumen via the vagina. Males have two testicles and one or several cement glands, which serve for locking up the female body after the copulation (Dezfuli et al., 1999)

Acanthocephalans have a two-host life cycle. A female releases eggs to the environment, these hatch and a first larva (acanthor) evolves. It enters the intermediate host (invertebrates), and in its hemocoel it evolves into the acanthella. Finally, it becomes cystacanth, a stage infectious for the final host (a vertebrate), where it lives in its intestine. Acanthocephalans usually enter gobies from invertebrates (especially belonging to the group Crustacea (Buron-Brun, 1986)) and finish their life cycle in gobies. Acanthocephala found in European marine gobies are summarised in Table 5.

The acanthocephalans affect their host mainly by the way they attach to its tissues. The acanthocephalans with a long neck, who penetrates deeply into the intestine wall, are more pathogenic

than those with a short neck and lesser penetration into the intestine wall (Taraschewski, 2000). Due to their small size, those belonging to the second group do not reach the peritoneal cavity and usually do not cause directly the death of their fish host. Nevertheless it has been shown that they affect the host's fitness and the females' reproductive success (Sasal et al., 2001). A change in the gonadosomatic index and egg production has been recorded in *Acanthocephaloides propinquus* (Dujardin, 1845) parasiting *Gobius bucchichi* Steindachner, 1870. It is explained by a high energetic cost of dealing with a parasite, so that the host does not have enough energy to produce eggs of a good quality (Sasal et al., 2001).

Like cestodans, acanocephalans can serve as bioindicators, as they are also very efficient in accumulating heavy metals (Taraschewski & Sures, 1996).

Table 5. Acanthocephalan parasites found in gobies and their goby hosts.

Hosts are written with the abbreviation of the sea (in parenthesis): B: Baltic Sea, M: Mediterranean, Bl: Black Sea, A: Atlantic, Ad: Adriatic Sea

References: 1: (Zander et al., 1999), 2: (Zander, 2004), 3: (Sasal et al., 1996), 4: (Zander, 2005a), 5: (Kvach & Oğuz, 2009), 6: (Amin et al., 2011), 7: (Sasal et al., 2001), 8: (Kvach, 2010), 9: (Kvach & Winkler, 2011), 10: (Kvach, 2007), 11: (Kvach, 2002), 12: (Kvach & Skóra, 2007), 13: (Abollo et al., 1998), 14: (Tepe & Oğuz, 2013), 15: (Sey, 1970a), 16: (Zander, 2003)

Parasite	Host	References
Echinorhynchus gadi Müller, 1776	*G. niger* (B), *P. microps* (B), *P. pictus* (B), *G. flavescens* (B), *N. melanostomus* (B), *P. minutus* (B)	1, 2, 4, 9, 16
Pomphorhynchus laevis (Müller, 1776)	*P. minutus* (B), *G. niger* (B), *N. melanostomus* (B)	1, 2, 9, 12, 16
Neoechinorhynchus rutili (Müller, 1780)	*P. minutus* (B)	
Acanthocephalus anguillae (Müller, 1780)	*P. pictus* (B), *G. flavescens* (B), *G. niger* (B), *P. minutus* (B)	2, 16
A. lucii (Müller, 1777)	*N. melanostomus* (B)	12
Acanthocephaloides propinquus (Dujardin, 1845)	*G. bucchichi* (M), *P. marmoratus* (Bl), *Po. marmoratus (*Bl), *N. melanostomus* (Bl), *N. ratan* (Bl), *N. eurycephalus* (Bl), *M. batrachocephalus* (Bl), *G. niger* (Bl), *Z. ophiocephalus* (Bl), *N. fluviatilis* (Bl), *G. paganellus* (A)	3, 5, 7, 8, 10, 11, 13
A. irregularis Amin, Oguz, Heckmann, Tepe, Kvach, 2011	*P. eurycephalus* (Bl), *P. marmoratus* (Bl)	6, 14
A. incrassatus (Molin, 1858)	*G. geniporus* (Ad), *G. cobitis* (Ad)	15
Telosentis exiguus (von Linstow, 1901)	*P. marmoratus* (Bl), *N. melanostomus* (Bl), *N. eurycephalus* (Bl), *Z. ophiocephalus* (Bl), *N. ratan* (Bl), *N. fluviatilis* (Bl)	5, 10, 11

3.6 Nematoda

Nematoda is one of the most species-rich phylum in the animal kingdom, although the parasitic are only a part of them (Rohde, 2005). They have a bilateral symmetry and they have usually shape of an elongate cylinder. Their size varies from 1 mm to more than 1 m in length (Roberts & Janovy, 2005). They have a pseudocoel filled with fluid and a complete digestive system with a mouth and an anus. Nematods are dioecious, sexually dimorphic and oviparous. Some of them are ovoviviparous. Hermaphroditism and parthenogenesis also occur. Nematodes go through four larval stages before they grow into an adult. Depending on the group, different stages are infectious for vertebrate hosts. In the Secernentea group, the infectious stage is L3 (third larval stage), whereas in the Adenophorea the infectious larvae is L1 (Rohde, 2005). Parasitic nematods can have a monoxenous life cycle (direct, without any intermediate host), or heteroxenous, which involves one or more intermediate hosts. In the marine environment, usually invertebrates (mostly polychaets and crustaceans) or various fishes serve as their intermediate hosts (Køie, 2001). Final hosts can be gobies as well as other fishes and birds (Zander, 1998a). Nematodes found in gobies are listed in Table 6.

The phylum Nematoda is divided into two classes: the Enoplea (i.e., Adenophorea, Aphasmidia) and the Rhabditea (Roberts & Janovy, 2005). Parasitic species are found in the enoplean subclass Dorylaimia and the Rhabditean subclass Rhabditia (i.e., Phasmidea, Sercenenta).

Table 6. Nematode parasites found in gobies and their goby hosts.

- Hosts are written with the abbreviation of the sea (in parenthesis): B: Baltic Sea, M: Mediterranean, Bl: Black Sea, A: Atlantic, Ad: Adriatic Sea

1: (Zander et al., 1999), 2: (Zander, 2004), 3: (Sasal et al., 1996), 4: (Zander, 2005a), 5: (M Malek, 2004), 6: (Kvach & Oğuz, 2009), 7: (Kvach, 2010). 8: (Kvach & Winkler, 2011), 9: (Kvach, 2007), 10: (Køie, 2001), 11: (Kvach, 2004), 12: (Kvach, 2002), 13: (Kvach & Skóra, 2007), 14: (Abollo et al., 1998), 15: (Tepe & Oğuz, 2013), 16: (Iglesias et al., 2013), 17: (Sey, 1970a), 18: (Petersen, 1992), 19: (Zander, 2003)

Parasite	Host	References
Hysterothylacium sp. Ward & Magath, 1917	*G. niger* (B), *G. flavescens* (B), *P. minutus* (B, A), *P. microps* (B, N, A), *P. pictus* (B, N)	1, 2, 4, 5, 18, 19
Hysterothylacium aduncum (Rudolphi, 1802)	*G. niger* (B, Bl), *P. microps* (B), *N. melanostomus* (B, Bl)	8, 13, 15
Contracaecum fabri (Rudolphi, 1819)	*G. geniporus* (Ad), *G. niger* (Ad)	17
Contracaecum sp. Railliet & Henry, 1912	*G. flavescens* (B, N), *P. microps* (B, N), *P. minutus* (B), *P. pictus* (N, B), *G. niger* (B)	1, 2, 19
Contracaecum rudolphii Hartwich, 1964	*M. batrachocephalus* (Bl)	11
Contracaecum aduncum (Rudolphi, 1802)	*G. cruentatus* (Ad) Gmelin, 1789 , *G. cobitis* (Ad)	17

C. clavatum Rudolphi, 1809	*G. niger* (Ad)	17
Cucullanus sp. Müller, 1777	*G. bucchichi* (M)	3
Cucullanus heterochrous Rudolphi, 1802	*P. minutus* (B), *P. microps* (B)	1
Raphidascaris sp. Railliet & Henry, 1915	*N. melanostomus* (Bl), *N. fluviatilis* (Bl)	9, 11
Raphidascaris acus (Bloch, 1779)	*P. microps* (B), *P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B)	1, 2, 19
Ascarophis arctica Poljansky, 1952	*P. microps* (B), *P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B)	1, 2, 19
Anisakis simplex (Rudolphi, 1809)	*P. microps* (B), *P. minutus* (B), *P. pictus* (B), *G. flavescens* (B), *G. niger* (B)	2, 19
Dichelyne minutus (Rudolphi, 1819)	*P. pictus* (B), *P. minutus* (A, N), *P. marmoratus* (Bl), *Po. minutus*, *N. melanostomus* (Bl, B), *N. ratan* (Bl), *N. eurocyphalus* (Bl), *M. batrachocephalus* (Bl), *G. niger* (Bl), *Z. ophiocephalus* (Bl), *P. microps* (N), *N. fluviatilis* (Bl)	2, 5, 6, 7, 9, 10, 11, 12, 13
Acuariidae Railliet, Henry & Sisoff, 1912	*P. microps* (A), *P. minutus* (A)	5
Streptocara crassicauda (Creplin, 1829)	*P. marmoratus* (Bl), *N. melanostomus* (Bl), *N. ratan* (Bl), *M. batrachocephalus* (Bl), *Z. ophiocephalus* (Bl)	6, 9, 11, 12
Contracaecum microcephalum (Rudolphi 1809)	*Po. marmoratus* (Bl)	7
Cosmocephalus obvelatus (Creplin, 1825)	*N. melanostomus* (B)	8
Eustrongylides excisus Jägerskiölt, 1909	*N. melanostomus* (B, Bl), *M. batrachocephalus* (Bl), *N. fluviatilis* (Bl), N. kessleri (Bl), *N. ratan* (Bl), *N. syrman* (Bl)	8, 11
Paracuaria adunca (Creplin, 1846)	*N. melanostomus* (B)	8
Camallanus lacustris (Zoega, 1776)	*G. niger* (B)	8
Anguillicoloides crassus Kuwahara, Niimi & Itagaki, 1974	*N. melanostomus* (B)	13
Capillaria sp. Zeder, 1800	*G. paganellus* (A)	14
Cystidicola sp. Fisher, 1798	*G. paganellus* (A)	14
Pseudocapillaria moraveci Iglesias, Centeno, García & García-Estévez, 2013	*G. paganellus* (A)	16

The type host of the nematode *Dichelyne minutus* (Rudolphi, 1819) in Scandinavian Atlantic is the flounder, *Platichthys flesus* (Linnaeus, 1758) (Pleuronectiformes). However, in the Black and

the Azov Seas it has been frequently recorded in gobies and moreover with the intensity of parasitation over one hundred (Naidenova, 1974). *D. minutus* can use fishes of families Gasterosteidae, Carangidae, Callionymidae, Gobiidae, Pleuronectidae and Soleidae as final hosts in the area of Black and Azov Seas (Greze et al., 1975), but Gobiidae are considered to be the most important ones.

Nematodes are endoparasites. In gobies they live in the gut, intestine, stomach, liver, muscle, or the body cavity (Iglesias et al., 2013; Kvach & Oğuz, 2009; Malek, 2004; Zander, 2004) and may be highly pathogenic (Koie, 2001). Adult nematodes move among the contents of the intestine on which they feed, although if there is no food available, they attach to the intestinal wall and feed on the intestinal tissue (Moravec, 1994). Their chitinous tooth can cause focal necrosis in the musculature (Rezae et al., 2013). The destruction of the intestinal vili and the necrotic and degenerative changes in the mucosal epithelium caused by nematodes may reduce the absorptive efficiency of the intestine of a fish (George & Nadakal, 1981). Nematodes can also restrict the food intake of the host by blocking the alimentary canal (Barber, 2007), for example, by a hyperplasia of the submucosa, which evokes formation of nodule-like structures accompanied by lifting up the connective tissue of the submucosa (Rezaei et al., 2013). A nutrition deficiency can directly affect the immune system (Gatlin, 2002) so parasitized animals are more susceptible to other infections (Sitjà-Bobadilla, 2008).

3.7 Crustacea

Crustacea are, together with Monogenea, the most speciose group of metazoan ectoparasites of marine fishes (Rohde, 2005). They belong to the phylum Arthropoda. They have a segmented body, an exoskeleton made mostly of chitin and calcium carbonate, and various appendages. The morphology of crustacean parasites can be simplified due to the parasitic style of life. This phenomenon is sometimes called “sacculinisation”. This term is derived from the name of rhizocephalan parasitic crustacean *Sacculina*, which parasitize on marine crabs (Phillips & Cannon, 1978). Its body consists of a sac-like structure called externa, which is attached to the ventral surface of the crab’s abdomen. It does not have any crustacean morphological structures. (Rohde, 2005)

There are two main groups of Crustacea, parasitizing Gobiidae: Isopoda and Copepoda. The literature on crustacean parasites of European marine gobies is scarce (Mercedes & Alberto, 2014; Raibaut et al., 1998; Van Damme et al., 1997) and only a few crustacean species were found up to date (see Table 7).

3.7.1 Copepoda

Copepoda is an extremely abundant group. It involves parasites, but also free-living species, which dominate the zooplankton, the biggest community of the planet (Rohde, 2005). Copepods exhibit sexual dimorphism, with a female having a pair of egg sac and being larger than males.

Copepodan life cycle comprises of up to six naupliar larval stages, followed by maximum five copepod stages and the adult stage. The copepodite stage has already a segmented body, all cephalic appendages and the first and second swimming leg. After each moulting, one somite is added. Normally, the infective stage of parasitic copepods is the first copepodid and they have only one host (Rohde, 2005). In some cases, they have a two-host life cycle, where mating occurs on the first host and producing of eggs on the second one (e.g., *Lernaeocera*) (Van Damme et al., 1997).

Gobies are not the most suitable hosts for copepods (Raibaut et al., 1998) due to their mostly benthic style of life and a small body size. Parasites can infect their goby hosts during their larval stages, or as an adult (e.g., *Caligus elongates* Nordmann, 1832, who can swim and can even change between hosts during its adulthood (Heuch et al., 2007)). They are found mainly on the gills (Maran et al., 2014) and the skin (Uyeno & Nagasawa, 2010). A list of Crustacea species found in European gobies can be seen in Table 7.

Parasitic copepods can affect their hosts directly by attaching to the host's body and feeding on host's tissue. The penetration of the skin causes local lesions that can be affected by secondary infections. Pressure necrosis and epidermal erosion might also arise and consequently the system of the fish responds with swelling, hyperplasia, proliferation of fibroblasts and cellular infiltration (Smith et al., 2007). The attachment to gills results in hypertrophy of the gills and fusion of secondary lamellae, with a consequent loss of respiratory surface area. Most copepods feed on the host epidermal tissue; therefore they can cause surface lesions, which can later result in hemorrhagia and anaemia (Toksen, 2007). Especially fishes parasitized by blood-feeders can be anaemic (Perkins et al., 2015). It has been suggested that parasitic copepods may serve as vectors of viral and bacterial diseases as they feed on host mucus, tissues and blood (Nylund et al., 1993).

3.7.2 Isopoda

Parasitic isopods usually feed on a host blood or haemolymph and for this purpose they use maxillipeds for tearing the flesh and mandibles for piercing into the tissue to penetrate blood vessels or blood sinuses. Two main groups parasitize fishes. These are Cymothoids and Gnathiids (Ravichandran et al., 2009).

Cymothoids parasitize on fish both as immature and adults. They are protandronous hermaphrodites. It means that the first male, who reaches the fish, switches to a female. Males, who come to the same fish afterwards, remain males. In some species males swim freely and stay with females on a fish just for the fertilisation, whereas males of other species live on the same host as a female the whole life. In European marine gobies, only a few species belonging to this group were found so far, with the most common being *Anilocra frontalis* Milne-Edwards, 1840 (Nieto & Alberto, 1994).

Table 7: A list of crustacean parasites found in gobies and their goby hosts.

- Hosts are written with the abbreviation of the sea (in parenthesis): N: North Sea, M: Mediterranean, Bl: Black Sea, A: Atlantic

1: (Zander, 2005a), 2: (Raibaut et al., 1998), 3: (Heuch et al., 2007), 4: (Ramdane et al., 2007), 5: (Van Damme, 1997), 6: (Kvach, 2004), 7: (Abollo et al., 1998), 8: (Nieto & Alberto, 1994), 9: (Tinsley & Reilly, 2002), 10: (Maran et al. , 2014), 11: (Petersen, 1992)

Parasite	Host	References
Caligus elongatus Nordmann, 1832	*G. flavescens* (N), *P. minutus* (N), *G. niger* (N), *Aphia minuta* (N) (Risso, 1810)	1, 3
Chondracanthus horridus Heller, 1865	*G. niger* (M)	2
Pharodes ninnii (Richiardi, 1882)	*G. auratus* (M), *K. panizzae* (M)	2
Taeniacanthus gobii (Brian, 1906)	*G. cobitis* (M)	2
Anilocra frontalis H. Milne Edwards, 1840	*G. flavescens* (M), *G. paganellus* (M, A), *P. minutus* (M), *Zebrus zebrus* (A)	4, 8
Nerocila bivittata (Risso, 1816)	*G. geniporus* (M)	4
Lernaeocera lusci (Bassett-Smith, 1896)	*P. minutus* (N), *P. lozanoi* (N)	5
Lernaeocera minuta (Scott, 1900)	*P. minutus* (N)	11
Ergasilus sieboldi sieboldi Nordmann, 1832	*N. ratan* (Bl)	6
Anchistrotos gobii Brian, 1906	*G. paganellus* (A), *G. cobitis* (M)	7, 10
Paragnathia formica (Hesse, 1864)	*P. microps* (N)	9

Gnathiidae are parasites of teleosts and elasmobranchs, and have a very interesting life-cycle. Their adult is always non-feeding and only larval stages are parasitic. As an example, I introduce here the life cycle of the isopod *Paragnathia formica* (Hesse, 1864) which parasitize a sand goby *P. microps* (Tinsley & Reilly, 2002). The life cycle consists of three free-swimming haematophagus larval stages and a non-feeding reproductive adult. This species starts its life cycle in autumn when female body ruptures and fully developed larvae are released (Upton, 1987). Larvae feed parasitically on estuarine fishes, especially on a goby *P. microps*, where they feed two to 24 hours (Stoll, 1962). Fed larva returns to the saltmarsh burrows, moults and continues its life cycle as a second and, subsequently, as a third larval stage, both feeding ectoparasitically. When it is fed, the third stage larva settles down to a burrow. Larvae reaching burrows of males from the previous year early in the season become females, whereas the later settling ones become males. Males have a harem of females in burrows and live 16 months whereas females live nine months and die after releasing larvae. *P. microps*, a host for their larvae, feeds mainly on crustaceans (Healey, 1972), therefore it is a host and a predator of *P. formica* at the same time (Tinsley & Reilly, 2002).

Apart from the direct impact by damaging skin of the fish host (which can have a mortal consequences for fry and fingerlings) and causing anaemia, the isopodans indirectly affect the fish by reducing its growth and inhibiting its reproduction (Ravichandran et al., 2009).

4 Additional effects on gobies

I have already described how each group of parasites can affect the health of gobies, but I still have not mentioned additional effects on the reproduction and on the behaviour of gobies. The reproduction of gobies involves parental care. Females lay their eggs in an area previously prepared by males. The male guards them until the larvae hatch out (Lindström, 1998). Thus female gobies search for nesting sites and food. Because of this mobility there is a higher probability for them to encounter more parasites (Pampoulie et al., 1999). This hypothesis contrasts with studies of parasitation of other animals including fishes, where males host more parasites than females (e.g., Poulin, 1996). A higher prevalence of parasites in males is usually explained by an immunosuppressive effect of a testosterone synthesis (Folstad & Karter, 1992).

During a paternal care males protect eggs from predators and fan them (Mazzoldi & Rasotto, 2001). They need to be in a good condition, because they cannot forage for food while guarding. Sometimes they eat some or all of their eggs to keep themselves alive over the length of the whole breeding season (Gross & Sargent, 1985). Parasites use their host´s recourses; therefore the host needs to ingest more food, or skip some activities in order to save energy (Lindström, 1998). Males of damselfishes *Stegastes planifrons* (Cuvier, 1830) (Pomacentridae) were examined and a positive correlation was found between a parasite load and a loss of eggs (Alduy, 2006). According to Alduy (2006), males could have eaten the eggs, or could have failed in defending them against predators. Some parasites (for example monogeneans located on the gills) can affect a breathing capacity and subsequently fanning activity of a male. In this regard there is another theory explaining the filial cannibalism. This theory says that male eats eggs in order to reduce a number of eggs which he fans (Alduy, 2006). There are no investigations on gobies in this view, but as they have the egg male care and a filial cannibalism is known to occur (Lindström, 1998), we can hypothesize that they can be affected similarly.

Males of *Pomatoschistus minutus* prepare nests by excavating sand under a shell (Hesthagen, 1977). There are some habitats where only limited space for making a nest is available. In these cases males compete with each other and usually those with a better body condition win (Barber, 2002). Parasites that reduce the body condition, such as for example the nematodan *Hysterothylacium* sp. and the copepod *Lernaeocera minuta* (Scott, 1900) (Petersen, 1992) also reduce the success of a fish to make a nest (Barber, 2002). Considering that all gobies make nests, this is a risk factor that applies for the whole family.

4.1 How does parasitism affect a female mate choice?

Representatives of Gobiidae have a very diverse range of reproductive behaviour. The mate choice can be influenced by parasites if they have an obvious morphological or behavioural effect on the host (Hamilton & Poulin, 1997), such as, for example, black spots on the skin caused by metacercariae of the digenean *Cryptocotyle lingua* (Rosenqvist & Johansson, 1995), or a reduced dorsal fin size caused by the monogenean *Gyrodactylus* sp. During a courtship and male-male interactions of gobies (Forsgren, 1995) the dorsal fin is erected. The reduced fin size in the individual parasitized by a *Gyrodactylus* species signalizes that this male is not in a good condition (Barber, 2002).

5 Evaluation of published literature on parasitation of European marine gobies so far

Although gobies are distributed along the whole European shoreline, work on their parasites is very scarce. There are many parasitological investigations on the guild of brackish water gobies of the Baltic Sea (e.g., Zander et al., 1999; Zander, 1998, 2003, 2004, 2005b). These works focus mainly on benthic gobies, such as *Gobius niger* Linnaeus, 1758, *Pomatoschistus microps, Pomatoschistus minutus, Pomatoschistus pictus* (Malm, 1865), and the hyperbenthic *Gobiusculus flavescens* (Fabricius, 1779). There are also works on goby parasites from other European seas, such as the North Sea (e.g., Picon-Camacho et al., 2009; Zander, 2005a), the Atlantic Ocean (e.g., Abollo et al., 1998; Freitas et al., 2009), the Mediterranean Sea (e.g., Raibaut et al., 1998; Sasal et al., 1996) and the Black Sea (e.g., Kvach & Oğuz, 2009; Kvach & Skóra, 2007), but they are not as exhaustive as the aforementioned studies. Most works usually focus on a description of a new parasite species (e.g., Longshaw et al. 2003; Amin et al., 2011), or on one group of parasites (e.g., (Bartoli et al., 2005; Raibaut et al., 1998)), but they do not take into account the host aspect. It should be also noted that relatively few of these studies exist outside the Baltic Sea even though quite a lot of gobies are described. For example, from the Mediterranean Sea, where 60 species of gobies are currently recognised (Ahnelt & Dorda, 2003; Kovačić & Golani, 2007; Kovačić, 2005) there are less works on goby parasitology than from the Black Sea, were only 33 species have been recorded (Boltachev et al., 2007; Freyhof & Naseka, 2007; Kovačić et al., 2009; Vasil'eva, 2003).

In addition, most works on parasitation of gobies are focused on goby species that are easy to collect by various types of nets. Several works are done on gobies that get stuck in tidal pools, from where they can be collected (e.g., *Gobius paganellus* (Iglesias et al., 2013; Nieto & Alberto, 1994), *Gobius cobitis* (Sasal et al., 1998) and *Zebrus zebrus* (Risso, 1827) (Nieto & Alberto, 1994)). The works on species which cannot be caught easily are scarce. The collection of such species is costly and time-consuming and combines scuba diving with the use of anaesthetic (Kovačić et al., 2012). Especially cryptobenthic species are not caught easily and works dealing with their parasite

communities lack. The similar situation is with the current knowledge on parasitation of hyperbenthic and nectonic gobies; only two such species have been studied so far.

Furthermore, some parasite groups parasitizing gobies are much more investigated (e.g. Nematoda, Digenea) than others (e.g. Myxozoa, Crusatcea).

6 Immunity of the fish

To infest the host, a parasite needs to overcome certain barriers. According to Holmes and Price (1986), the infestation of hosts by parasites can be compared to the colonisation of islands (MacArthur, 1967). The host immune system corresponds to a distance from the mainland to the island and the size of the host corresponds to the island size. Thus more parasites can be harboured by a bigger host (Nieto & Alberto, 1994) and better the immune system of the fish is, less parasites can defeat it.

The immune system of teleost fishes is composed of a non-specific and specific part (Dalmo et al., 1997) and humoral and cell-mediated mechanisms function (Secombes, 1996). First line of defence is created by the humoral non-specific defence in mucosa including proteases, lysins and agglutinins. Mucosal lining cells are the second line of protection, followed by blood cells – granulocytes and monocytes. For the final destruction of the intruder endothelial cells, macrophages and granulocytes are responsible. They are able to degrade microbes or microbial products and their function is connected to the rethiculoendothelial system (Dalmo et al., 1997).

I did not find research directly characterising immune reactions of gobies, but some indirect evidences of defence mechanisms in terms of a host-parasite relationship exist. For example, in the southwestern Baltic Sea the digenean *Podocotyle atomon* has usually high abundances, but in *G. niger* this species was often absent, which was explained by its immune system efficiency (Zander et al., 1999; Zander, 1993). Other example is *P. minutus* that must have a better immune defence than other gobies from the Baltic Sea, because the prevalences and intensities of various parasites were usually lower (Zander et al., 1993).

7 Metazoan parasites of brackish waters

The distribution of parasites depends partly on the adaptation abilities of their hosts (Zander & Reimer, 2002). On the other hand, parasites can be widely distributed, because they can have a greater tolerance to lower and changing salinity (Kesting & Zander, 2000). Therefore parasites rather expand their host spectrum, which is facilitated by the osmotic stress in brackish waters (Zander, 1998b). In brackish waters we can find a combination of marine, fresh water and a “genuine brackish species” (marine species adapted to the salinity changes) (Zander, 1998a).

The largest European brackish areas are the Baltic and the Black Seas. In the Baltic Sea the salinity descreases from Skagerak (Norway) to the Gulf of Finland, which is almost limnetic. The most stable is the central Baltic Sea with the salinity of 6-8 ‰ (Zander et al., 1999; Zander, 1998a). The parasitic fauna of this sea comprises of marine species (e.g., the digeneans *Derogenes varicus* (Müller, 1784), *Podocotyle atomon*, *Cryptocotyle lingua*, the cestode *Bothriocephalus scorpii* (Müller, 1776) , the nematodans *Hysterothylacium aduncum* (Rudolphi, 1802) and *Anisakis simplex* (Rudolphi, 1809) and the acanthocephalan *Echinorhynchus gadi)*, limnetic species (e.g., digenean *Diplostomum spathaceum* (Rudolphi, 1819), the cestode *Schistocephalus solidus*, the nematodan *Anguillicoloides crassus* Kuwahara, Niimi & Itagaki, 1974, and the acanthocephalans *Pomporhynchus laevis* and *Neoechinorhynchus rutili* (Müller, 1780)) and genuine brackish water species (e.g., the digeneans *Cryptocotyle concavum*, *Aphalloides timmi* and *Maritrema subdolum* Jägerskiöld, 1909) (Zander, 1998a). An example of a genuine water species among goby hosts is *P. microps*, which in the Schlei Fjord (Baltic Sea, Germany) at the point of minimum species (Remane & Schlieper, 1958) harbours the highest number of parasite species (Kesting et al., 1996; Zander, 2003). A point of "minimum species" is a locality with brackish water of a salinity lower than 8 ‰ (Kesting & Zander, 2000).

Due to the adaptation to the changing salinity, parasites sometimes modify their life cycle. A first modification can be a shortening of the cycle. An example is *Microphallus claviformis* (Brandes, 1888) (Digenea), whose first intermediate host is *P. microps* and its second intermediate host is normally a benthic crustacean, but in the Baltic Sea it goes directly from the goby to the final host and omits the second intermediate host (Zander, 1998a). *A. timmi* (Digenea) has a different strategy: it infests its final host, *P. microps*, immediately after leaving the snail (the intermediate host), without having a second intermediate host (Reimer, 1970). On the other hand, extension of the life cycle of a parasite also occurs in brackish waters. *M. subdolum* (Digenea) extends its cycle by having more intermediate fish hosts among various fishes of brackish waters (Reimer, 1963). Due to specific conditions in brackish waters more generalists than specialists among parasites occur (Kesting et al., 1996). For example, the plerocercoids of the tapeworm *S. solidus* normally parasitize the three-spined stickleback (*Gasterosteus aculeatus*, Gasterostiformes) as the intermediate host, but in the Baltic Sea it is found in at least three goby species (Zander, 1998a).

A comparative study of a parasite communities of three goby species (*P. microps, G. flavescens, P. pictus*) of a marine (North Sea) and a brackish water (Baltic Sea) has been made (Zander, 2005a). The number of species in both seas was similar, although in the Baltic Sea the abundance and prevalence of most parasites was higher. It is explained mainly by the accessibility of intermediate hosts. In the Baltic Sea, most of the phenomena from brackish waters of modification of a parasite life cycle, as I described above, were confirmed. I will mention an example of a reduction of host specificity. The digenean *Cryptocotyle lingua* infects only a snail *Littorina littorea* (Linnaeus,

1758) (Littorinidae, Gastropoda) among snails in the North Sea, but in the Baltic Sea it uses also a snail *Peringia ulvae* (Pennant, 1777) (Hydrobiidae, Gastropoda) as its first intermediate host (Zander et al., 2000).

8 The effects of eutrophication on parasites

The eutrophication is caused by human activity and it is becoming a serious problem (Fei, 2004). It is a result of an increased input of nutrients, which promotes the growth of algae and water plants. This is profitable for herbivores and detritovores (e.g., snails and crustaceans), the preferred intermediate hosts of most parasite groups (Zander, 1998a). Therefore the eutrophication can be profitable for parasites. However, the organic matter is converted by microorganisms into inorganic substances and the process of this conversion consumes oxygen. The lack of oxygen (anoxia) in the lower water layers, often combined with the increase in content of toxic substances, can affect the whole ecosystem, and therefore also hosts, as well as free living stages of endoparasites (especially larvae) and ectoparasites (Zander, 1998a). The lack of oxygen is usually the greatest at the bottom and it can have a negative effect on a bottom dwelling communities, where the majority of gobies belong (Kovačić & Patzner, 2011). In some heavily eutrophicated situations benthic parasites can totally disappear due to the disappearance of their hosts and only planktonic parasites with a one-host cycle remain (Kesting et al., 1996).

Due to the environmental stress the immune system of the host fails and parasites (especially endoparasites) can profit from that, as it is easier to infest the host. In the eutrophicated environment, mechanisms like modification or shortening of a parasite life cycle can occur (Zander et al., 1999).

In the eutrophicated environment common parasites become abnormally abundant, while these conditions suppress the occurrence of rare ones. It has been proved that under such conditions, gobies exhibit high parasite prevalence and a low parasite diversity. Moreover generalist parasites dominate over specialists (Zander & Kesting, 1996; Zander, 1998b; Zander, 1993). Effects on parasite and host population in conditions of eutrophication can be seen in Figure 4.

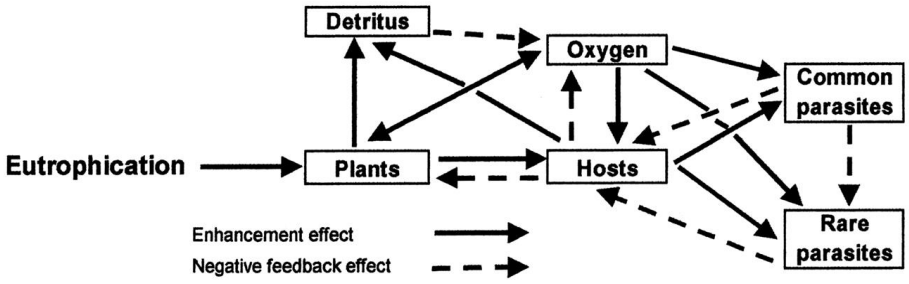

Fig. 4. Model effects on parasite and host population under eutrophication, taken from Zander (2011).

9 The difference in the level of parasitism in protected and unprotected areas

The parasitism of *Gobius bucchichi* in and around the marine reserve Cerbère-Banyuls (French Mediterranean) has been studied by Sasal et al. (1996). Fishes from the reserve were more abundant, older and larger, and had a higher percentage of regenerated scales, but also harboured more parasites. This means that the abundance of parasites depends mainly on the abundance and size of the host (Arneberg et al., 1998). A small fish has only a limited number of potential infection sites. In many studies a positive correlation of a host size and a number of parasites has been observed (Mercedes & Alberto, 2014; Sasal et al., 1997; Zander, 2004). In a protected area generalist parasites can have a very high abundance due to the high abundance of potential hosts (including the intermediate hosts), whereas specialists do not have any advantage if their specific host is not favoured.

10 Conclusion

Studies on metazoan parasites of marine European gobies are scattered. Nevertheless, parasites of gobies deserve more attention considering the importance of these fishes in the ecosystem. Parasitation of gobies in some European seas has been studied well (e.g., Baltic Sea), but in most other seas has been studied poorly (especially in the Mediterranean Sea). Published works are done mostly on similarly living gobies as for example *P. microps*, *P. minutus*, *G. niger* (benthic species living on soft substrates), therefore the comparison of parasites with different ecological strategies is not possible so far. Although several species of gobies with different ecological strategies have been studied as well (e.g., *G. bucchichi*, *G. paganellus* – benthic species living on hard substrate), the available information on parasitation is not consistent, so it is not possible to make any conclusions about the difference in parasitation between species from different habitats. Moreover, parasites were researched only in two nectonic or hyperbentic goby species, while there is only one work on one cryptobenthic goby species. This is given by the difficulty of obtaining the goby species by other means then various kinds of nets. Cryptobenthic goby species and most benthic ones living on a hard substrate cannot be caught on this way.

The effects of a parasite on a goby are rarely described. There is a big difference also in the number of parasite species found in gobies belonging to different groups of parasites. While the list of representatives of Digenea and Nematoda is quite long, the number of myxozoan or crustacean parasites is very small. This suggests the need of investigating certain parasite groups.

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